TG: @Chalnaayaaar

Electrostatics

SOLUTIONS

Beginner's Box - 1

1. $Q = ne$ = 10% of $5 \times 10^{21} \times 1.6 \times 10^{-19}$

$Q = 80C$

2. Number of moles in 100 g of $CO_2 = \frac{100}{44}$ mole

and Number of electrons in one mole of $CO_2 = 22\ N_A$

so Number of electron in 100 g of CO_2

$= \frac{100}{44} \times 22\ N_A = 50\ N_A = 50 \times 6.023 \times 10^{23}$

$= 3 \times 10^{25}$ electron.

3. $N = \frac{Q}{e}$, if N is not an integer then Q is not possible.

4. Q = Number of ion × charge of each ion

= (1 billion × 2) × (+e) (1 billion = 10^9)

$= 2 \times 10^9 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-10}$ C

5. Charge Q = Ne

$\Rightarrow N = \frac{Q}{e} = \frac{3.5 \times 10^{-9}}{1.6 \times 10^{-19}} = 2.18 \times 10^{10}$

6. For proton $\Rightarrow$ u, u, d and

For neutron $\Rightarrow$ d, d, u

7. (a) $\because Q = Ne$

$\therefore \quad N = \frac{Q}{e} = \frac{3.2 \times 10^{-7}}{1.6 \times 10^{-19}} = 2 \times 10^{12}$

(b) Mass gained = Nm_e

$= 2 \times 10^{12} \times 9.1 \times 10^{-31}$

$= 18.2 \times 10^{-19}$ kg

8. A will have positive charge and B will have negative charge.

Beginner's Box - 2

1. $|\vec{F}| = \frac{kq(2q)}{r^2} = \frac{2kq^2}{r^2}$

Charges on spheres after contact

$= \frac{q - 2q}{2} = -\frac{q}{2}$

$|\vec{F}_{new}| = \frac{K\left(\frac{-q}{2}\right)\left(-\frac{q}{2}\right)}{r^2}$

2. $F = \frac{kq^2}{r^2} \Rightarrow q = r\sqrt{\frac{F}{k}} = 5 \times 10^{-10}\sqrt{\frac{4 \times 10^{-9}}{9 \times 10^9}}$

$\Rightarrow q = 5 \times 10^{-10} \times \frac{2}{3} \times 10^{-9}$

$\Rightarrow q = \frac{10}{3} \times 10^{-19} \Rightarrow n = \frac{q}{e} \simeq 2$

3. In equilibrium, forces are in balancing condition $F_g = F_e$

$\Rightarrow \frac{GM^2}{d^2} = \frac{KQ^2}{d^2}$

where d is the distance between charges

$\Rightarrow \frac{Q^2}{M^2} = \frac{G}{K}$

$\frac{Q}{M} = \sqrt{\frac{G}{K}} = \sqrt{\frac{6.6 \times 10^{-11}}{9 \times 10^9}} = 0.85 \times 10^{-10}$

4. $F \propto \frac{1}{r^2}$

So $\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2} \Rightarrow \frac{100}{F_2} = \frac{\left(\frac{3}{2}r\right)^2}{r^2}$

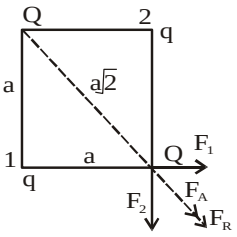
[Here $r_2 = r + 50\%r = r + r/2 = 3r/2$]

$\Rightarrow \quad F_2 = \frac{400}{9}\text{N} = 44.4\text{N}$

5. $q = r\sqrt{\frac{F}{k}} = 4 \times \sqrt{\frac{3.6}{9 \times 10^9}} = 4 \times \frac{6}{3 \times 10^5} = 8 \times 10^{-5}\text{C}$

$n = \frac{q}{e} = 5 \times 10^{14}$

6.



If Net force on Q is zero

$\vec{F}_{net} = \vec{F}_R + \vec{F}_A = \vec{0}$ where F_A = Resultant of F_1 and $F_2 = \sqrt{2}\frac{kQq}{a^2}$

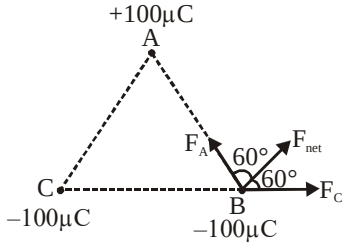
$$\Rightarrow \frac{kQ\,Q}{(\sqrt{2}a)^2}+\sqrt{2}\frac{kQ\,q}{a^2}=0$$

$$\Rightarrow \frac{kQ^2}{2a^2}+\frac{k\sqrt{2}Qq}{a^2}=0 \Rightarrow \frac{Q}{2}+\sqrt{2}q=0$$

$$\Rightarrow \frac{Q}{2}=-\sqrt{2}q$$

so $q=-\frac{Q}{2\sqrt{2}}=-\frac{\sqrt{2}}{2\sqrt{2}}=\frac{1}{2}-\mu C$ $\left[Q=\sqrt{2}\mu C\right]$

7.



$F_{net}=2F\cos\frac{\theta}{2}=2F\cos\left(\frac{120^\circ}{2}\right)$

$=F=\frac{kQ^2}{r^2}$ $\quad\because (F_A=F_C=F)$

$=\frac{9\times10^9(100\times10^{-6})\times(100\times10^{-6})}{(10\times10^{-2})^2}$

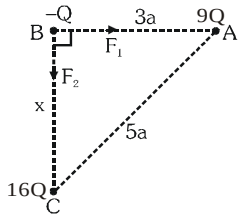
$= 9 \times 10^3$ N parallel to CA

8. Repulsive force $F=\frac{kQ^2}{r^2}=mg$

$\Rightarrow \frac{9\times10^9\times(1.6\times10^{-19})^2}{d^2}=1.7\times10^{-27}\times9.8$

$\Rightarrow d=\sqrt{\frac{9\times10^9\times(1.6\times10^{-19})^2}{1.7\times10^{-27}\times9.8}}=0.118$ m

9.



$x=\sqrt{(5a)^2-(3a)^2}=4a$

$F_1=\frac{kQ9Q}{(3a)^2}$ and $F_2=\frac{kQ16Q}{(4a)^2}$

$F_1=F_2=\frac{kQ^2}{a^2}$

$F_{net}=\frac{\sqrt{2}\,kQ^2}{a^2}$

10. For circular motion of Q, $F_{CP}=F_e$

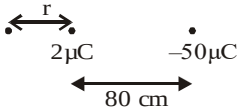
$\Rightarrow \frac{mv^2}{R}=\frac{kQq}{R^2}\Rightarrow v=\sqrt{\frac{kQq}{mR}}$

$\Rightarrow$ Time period $T=\frac{2\pi R}{v}=\frac{2\pi R\sqrt{mR}}{\sqrt{kQq}}$

$\Rightarrow T^2=\frac{4\pi^2R^2(mR)4\pi\epsilon_0}{(Qq)}=\frac{16\pi^3\epsilon_0 mR^3}{Qq}$

Beginner's Box - 3

1. For null point



Net intensity = 0

So, $\frac{kQ_1}{r_1^2}=\frac{kQ_2}{r_2^2}$

$\frac{Q_1}{Q_2}=\frac{r_1^2}{r_2^2}\Rightarrow\frac{r_1}{r_2}=\sqrt{\frac{Q_1}{Q_2}}$

here $r_1 = r$, $r_2 = 80 + r$

$|Q_1| = 2\ \mu C$, $|Q_2| = 50\ \mu C$

$\Rightarrow \frac{r}{80+r}=\sqrt{\frac{2}{50}}=\frac{1}{5}$

$\Rightarrow r = 20$ cm

2. For balancing $qE = mg$

$qE = 2 \times 10^{-6}g$ (1 miligram = 10^{-6} kg)

$q=\frac{2}{4}\times10^{-5}=5\times10^{-6}$ C

Nature of charge will be positive

3. $qE = mg \Rightarrow q=\frac{mg}{E}=\frac{10\times10^{-6}\times10}{100}$

$q = 1 \times 10^{-6}$

$n=\frac{q}{e}=\frac{1\times10^{-6}}{1.6\times10^{-19}}=6.25\times10^{12}$

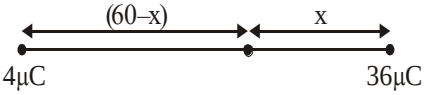
4. Electric field $\vec{E}=\frac{\vec{F}}{q}=\frac{5\times10^{-2}\hat{j}}{2\times10^{-6}}$

$= 2.5\times10^4\ \hat{j}$ N/C

$\therefore |\vec{E}| = 2.5\times10^4$ N/C

electric field along y-direction

5. Let at x distance from bigger charge E = 0

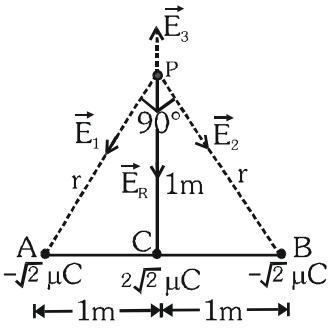


$$\frac{k(36)}{x^2}=\frac{k(4)}{(60-x)^2}=\frac{9}{x^2}=\frac{1}{(60-x)^2}$$

$$\Rightarrow \quad \frac{3}{x}=\frac{1}{60-x}\Rightarrow \quad 180-3x=x$$

$$\Rightarrow 180=4x \Rightarrow x=45 \text{ cm}$$

6.



Electric field $E_1 = E_2 = \frac{kq}{r^2}$

$[\because\ r=\sqrt{2}\,m; q=\sqrt{2}\mu C; q'=2\sqrt{2}\mu C]$

$$=\frac{9\times10^9\times\sqrt{2}\times10^{-6}}{(\sqrt{2})^2}=6.36\times10^3\ N/C$$

Resultant electric field $E_R=2E_1\cos\frac{90°}{2}$

$$=2\times6.36\times10^3\times\frac{1}{\sqrt{2}}=9\times10^3\ N/C$$

$$E_3=\frac{kq'}{(PC)^2}=\frac{9\times10^9\times2\sqrt{2}\times10^{-6}}{(1)^2}$$

$$=18\sqrt{2}\times10^3\ N/C$$

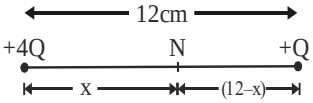
$\therefore E_{net}=E_3-E_R=18\sqrt{2}\times10^3-9\times10^3$

$=16.46\times10^3\ N/C$

Direction of net electric field is perpendicular and away from the line AB

Beginner's Box - 4

1.



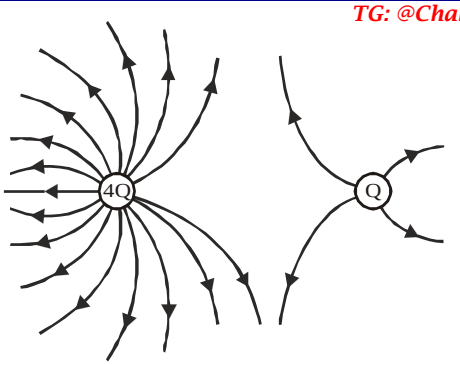
At neutral point N, the total field is zero.

Let it be at a distance x from 4Q

then $\frac{1}{4\pi\epsilon_0}\frac{4Q}{x^2}=\frac{1}{4\pi\epsilon_0}\frac{Q}{(12-x)^2}$

$$\Rightarrow\frac{(12-x)^2}{x^2}=\frac{1}{4}\Rightarrow\frac{12-x}{x}=\frac{1}{2}$$

$\Rightarrow 24-2x=x \Rightarrow 3x=24 \Rightarrow x=8$ cm



2. Surface charge density for non conducting plate $\sigma_{NC}=\frac{Q}{A}$ and

$$E_{NC}=\frac{\sigma}{2\epsilon_0}=\left(\frac{Q}{A}\right)\times\frac{1}{2\epsilon_0}=\frac{Q}{2\epsilon_0 A}=20V/m$$

For conducting plate $\sigma_C=\frac{(Q/2)}{A}=\frac{Q}{2A}$

and $E_C=\frac{\sigma}{\epsilon_0}=\left(\frac{Q}{2A}\right)\times\frac{1}{\epsilon_0}=\frac{Q}{2\epsilon_0 A}=20\ V/m$

3. Net flux = Zero, because the number of lines entering the cube is same as the number of lines leaving the cube.

4. Electric flux depends on the total charge enclosed by the closed surface S. Hence flux is related with charge Q_1. Electric field at a point is the vector sum of the all electric field intensities due to all charges.

5. If the cube would have 6 faces then total flux through 6 faces = $\frac{Q}{\epsilon_0}$

Total flux through one face = $\frac{Q}{6\epsilon_0}$

Hence flux through given cube = $\frac{5}{6}\frac{Q}{\varepsilon_0}$

6. Electric Flux = $\frac{q}{\epsilon_0}=\frac{2\times10^{-6}}{8.85\times10^{-12}}$

$=2.25\times10^5\ Nm^2/C$

7. (a) From Gauss theorem $\phi=\oint_s\vec{E}.d\vec{s}=\frac{q}{\epsilon_0}$

$\Rightarrow q=\phi\times\epsilon_0$

$=(-6\times10^{-3})\times(8.85\times10^{-12})$

$=-5.31\times10^{-14}$ C

(b) Flux remains the same

8. All i.e. q_1, q_2, q_3 & q_4

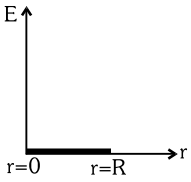
9. Yes, *Ex :* A dipole is placed in closed surface

10. (a) Zero

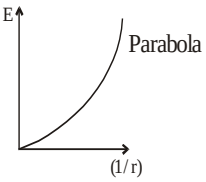
(b) Electric field

$$E=\frac{\sigma}{\epsilon_0}=\frac{17\times10^{-12}}{8.85\times10^{-12}}=1.92\ V/m$$

11. (a)



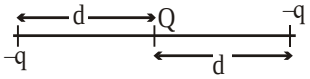
(b)



$$E=\frac{kq}{r^2},E\propto\left(\frac{1}{r}\right)^2,y\propto x^2$$

Beginner's Box - 5

1.



$$U_{system}=-\frac{KqQ}{d}-\frac{KQq}{d}+\frac{Kq^2}{2d}=0$$

$$\Rightarrow\frac{2kQq}{d}=\frac{kq^2}{2d}\Rightarrow\frac{Q}{q}=\frac{1}{4}$$

2. $W = q\Delta V$

$\therefore\ \Delta V = 0$

$\Rightarrow W = 0$ (equipotential surface)

3. $$U_i=-\frac{2kq^2}{a}+\frac{4ka^2}{a}-\frac{2kq^2}{a}=0$$

$$U_f=-\frac{2kq^2}{2a}+\frac{4ka^2}{2a}-\frac{2kq^2}{2a}=0$$

$W = \Delta U = U_f - U_i = 0$

4. $$\frac{ke^2}{10\times10^{-2}}=\frac{ke^2}{20\times10^{-2}}+2\times\frac{1}{2}\times mv^2$$

$\Rightarrow v \simeq 36\ m/s$

5. (i) Potential energy $U=\frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$$=9\times10^9\times\frac{7\times(-2)\times10^{-12}}{0.18}=-0.7\ J$$

(ii) Work required $= -U = -(-0.7)\ J = 0.7\ J$

6. (i) Potential $V=\frac{kQ}{r}=\frac{9\times10^9\times4\times10^{-7}}{9\times10^{-2}}$

$= 4\times10^4\ V$

(ii) Work done $W = q(V_f - V_i)$

$= 2\times10^{-9}(4\times10^4 - 0) = 8\times10^{-5}\ J$

$(V_i = V_\infty = 0)$

No, it is not depending on the path.

7. (a) Potential at centre of hexagon is

$$V=6\times\frac{kq}{a}=\frac{6\times9\times10^9\times5\times10^{-6}}{0.1}\ volt$$

$= 27\times10^5\ V$

8. $$\Delta V = KQ\left[\frac{1}{r_1}-\frac{1}{r_2}\right]$$

$$=9\times10^9\times5.5\times10^{-6}\left[\frac{1}{0.2}-\frac{1}{0.1}\right]$$

$= 2.475\times10^5$ volts

The point 20 cm away from charge is at higher potential

9. (i) $V=\frac{KQ}{r}\Rightarrow r=\frac{KQ}{V}=0.54m$

(ii) If r becomes four times then

$$V_{new}=\frac{V}{4}=2.5KV$$

$\Delta V = 7.5$ kV, Decrease

10. $$V=\frac{KQ_1}{r}+\frac{KQ_2}{r}+\frac{KQ_3}{r}$$

where r is distance of centre from vertex

$r = 2/3\ (20\sin60°)\times10^{-2}\ m$

$$\Rightarrow\quad r=\frac{0.2}{\sqrt{3}}m$$

$$So\ V=\frac{K\times4\times10^{-6}}{\frac{0.2}{\sqrt{3}}}=3.1\times10^5\ V$$

11. Potential at centre $V=\frac{k(Q_1+Q_2+Q_3+Q_4)}{r}$

$$r=\frac{0.1}{\sqrt{2}}m$$

$$V=\frac{k(-30\times10^{-6})}{\frac{0.1}{\sqrt{2}}}=-38.88\times10^5\ V$$

$\simeq -3.8\times10^6\ V$

12. Electric field $\vec{E}=-\frac{\partial V}{\partial x}\hat{i}-\frac{\partial V}{\partial y}\hat{j}-\frac{\partial V}{\partial z}\hat{k}$

$$=-(2x)\hat{i}-(-2y)\hat{j}-2\hat{k}=2x\,\hat{i}+2y\,\hat{j}-2\hat{k}$$

At point (1,1,1)

$$\vec{E}_P=-(2\times1)\hat{i}+(2\times1)\hat{j}-2\hat{k}$$

$$=-2\hat{i}+2\hat{j}-2\hat{k}$$

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13. $\frac{kQ}{R} = V$

$\Rightarrow \frac{9\times10^{9}\times3.5\times10^{-6}}{R} = 2.5 \times 10^{3}$

$\Rightarrow R = 12.6$ m

14. (i) $\Delta V = E \times d = 3 \times 10^{4}$ volt

decreases in direction of electric field lines and vice versa.

(ii) $W = q\Delta V \therefore \Delta V = 0 \Rightarrow W = 0$

15. (a) $V_P > V_Q$ so $V_P - V_Q$ is positive

$V_B > V_A$ so $V_B - V_A$ is positive

(b) $U_Q = (-q)V_Q$, $U_P = (-q)V_P$

$U_Q - U_P = q(V_Q - V_P) \Rightarrow$ positive

similarly $U_A - U_B = -q(V_A - V_B)$

$\Rightarrow$ positive

(c) $W_{agent} = q(V_f - V_i) = q(V_P - V_Q)$ is positive so $W_{field} = -W_{by} \Rightarrow W_{by}$ field is negative

(d) $W_{agent} = (-q)(V_A - V_B) \Rightarrow$ is positive

(e) Decreases

Beginner's Box - 6

1. $\tau_{max} = PE = 3.4 \times 10^{-30} \times 2.5 \times 10^{4}$

$= 8.5 \times 10^{-26}$ N-m

2. $\because$ Potential energy $= -PE\cos\theta$

for minimum potential energy $\theta = 0°$

3. $\tau = PE \sin\theta = q(d)E \sin\theta$

$q = \frac{\tau}{dE\sin\theta} = \frac{8\times\sqrt{3}}{4\times10^{-2}\times4\times10^{5}\sin60} = 10^{-3}C$

4. Since particle (1) and (2) are deflected opposite to E so particle (1) and (2) are negatively charged and (3) is positively charged.

The displacement $y \propto \left(\frac{Q}{m}\right)$ therefore particle (1) has highest charge to mass ratio.

5. Time taken by electron to travel 1 cm,

$t = \frac{x}{v} = \frac{10^{-2}}{10^{6}} = 10^{-8}s$

In this time it is deflected a distance antiparallel to the field which is given by –

$y = \frac{1}{2}at^2 = \frac{1}{2}\left(\frac{eE}{m}\right)t^2$

$= \frac{1}{2}\times\frac{1.6\times10^{-19}\times200}{9.1\times10^{-31}} \times 10^{-16} = 0.176$ cm

6. Total charge $= 2.5 \times 10^{-7} - 2.5 \times 10^{-7} = 0$

Dipole moment $\vec{p} = (qd)\left(-\hat{k}\right)$

$= -(2.5\times10^{-7} \times 30 \times 10^{-2})\,\hat{k} = -7.5\times10^{-8}\hat{k}$

Beginner's Box - 7

1. For any metallic surface, electric field lines are perpendicular to the surface.

2. 1, 2, & 3 are wrong because in metallic solid sphere, there is no field inside the sphere. Option (4) is correct from given reason and also it has field lines perpendicular to the surface (as required in metallic surface)

3. Due to the induction, the opposite nature of charge is induced at near by surface.